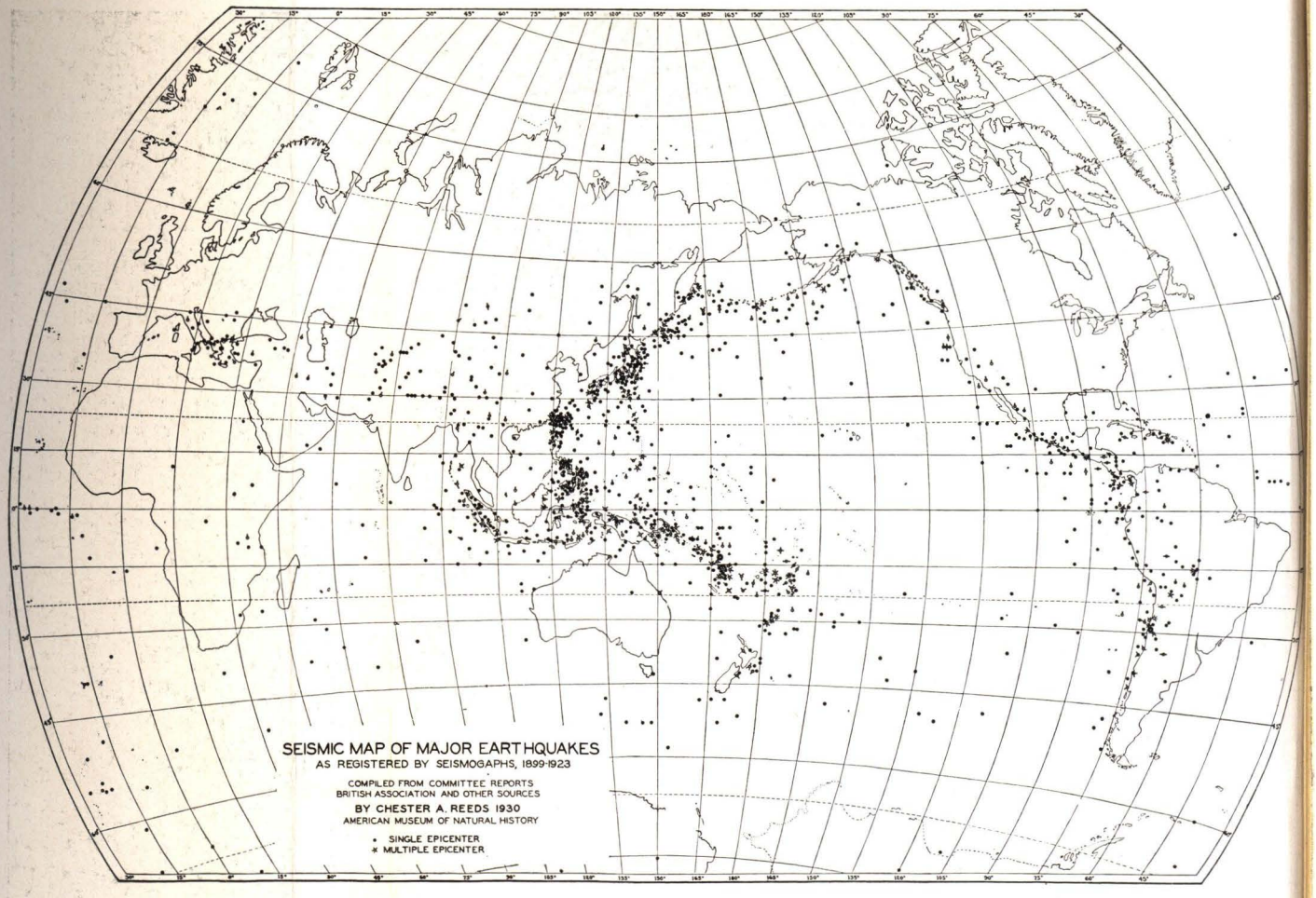

This map of the world shows the earthquake belt that girdles the globe. This map is one of several compiled by Dr. Chester A. Reeds, Curator of Geology of the American Museum of Natural History.

MORE ABOUT EARTHQUAKES

by

B. GUTENBERG

(NOTE: The SKY takes pleasure in presenting the following article on earthquakes and where they occur by Dr. Gutenberg of the Balch Graduate School of Geological Sciences, California Institute of Technology. It is complementary to the earthquake articles by Dr. Chester A. Reeds and N. H. Heck that appeared in the March issue of The SKY.—The Editor.)

THE number of earthquakes is very much larger than is generally believed. It has not been possible as yet to estimate the total number of earthquakes which occur during a single year strong enough to record on instruments if any are close to the source, but this number probably exceeds 1,000,000 per year. Between 10 and 100,000 shocks each year are strong enough to be felt generally near the epicenter if people happen to be there. A few hundred shocks yearly are registered over at least half the surface of the earth. The strongest shocks, which have more than ten thousand times the energy of most of the shocks just mentioned, occur on an average of one a year, roughly. The strongest shocks which have been recorded during the last thirty-five years are the shocks of January 31, 1906, in Ecuador and Colombia, of January 3, 1911, in Turkestan, of December 16, 1920, in Kansu, China and of November 11, 1922, in the Chilean province of Atacama. Among the six next strongest shocks during the same time is the San Francisco earthquake of April 18, 1906. Relatively strong shocks in the continental United States in recent years, but with less than one-tenth of the energy of the San Francisco earthquake, include the Nevada earthquake of December 20, 1932, the much smaller shock of November 1, 1935, which had its source in Canada but was felt over a large area in the United States, the Montana earthquakes of June 28, 1925, and of October 18 and October 31, 1935, the Utah earthquake of March 12, 1934. About the same size as the last mentioned, with about one-thousandth of the energy of the San Francisco shock, was the Texas earthquake of August 16, 1931, while the two California shocks of Santa Barbara, June 29, 1925, and of Long Beach, March 10, 1933, were slightly smaller still. Among the strong shocks which have occurred in the United States before instrumental records were available, the New Madrid (Missouri) earthquakes of 1811/12 and the Charleston (South Carolina) earthquake of 1886 had exceptionally great energy.

Earthquakes occur in all regions of the earth. However, there are certain regions where they are very much more frequent than in others. More than half of all earthquakes are found in a relatively narrow belt around the Pacific Ocean, which includes Kamchatka, the Kurile Islands, and Japan, where it splits into two sections, one running through the Marianne Islands and the other across the Philippine Islands to the central and eastern East Indies, New Guinea, the Solomon Islands, New Hebrides and Fiji Islands, then in a more southwesterly direction through the Tonga and Kermadec deeps to New Zealand. From there on

the exact location is not yet well known, partly because, apparently, a smaller number of shocks occur in that region and partly because of the lack of seismological stations there. It probably goes through the southern part of the Pacific Ocean to South America where there is large activity along the coast region. Frequent shocks are observed in Central America and Mexico and then, with decreasing number and intensity, in the western parts of the United States and Canada; while the number and magnitude again increases through southwestern Alaska and the Aleutian Islands. Another belt of large seismic activity covers southern Asia and the Mediterranean regions. Many minor structures such as the Mid-Atlantic ridge and the rift valleys in northeast Africa show activity above average.

Studies of earthquake waves have shown that the crust of the earth consists of two major units. One is the Pacific Ocean basin with the boundaries given by the Earthquake belt which has just been mentioned and the other unit consisting of the whole remaining part of the earth's crust. This latter part has surface layers consisting of granitic material on top and more basic material below. The thickness of this so-called continental crust varies. It seems to be thickest (about 30 miles) under the large mountain areas, the thinnest (of the order of 10 miles) under the Atlantic and Indian Oceans. It is completely absent in the basin of the Pacific Ocean. The boundary between these two units is marked not only by the earthquake belt but also by the fact that the waves are propagated very much faster along the bottom of the Pacific Ocean than in any part of the other unit and that waves travelling across this boundary lose an appreciable amount of their energy. Other properties of the waves produced by earthquakes indicate the same facts. The Atlantic and Indian Oceans must, therefore, be considered as large "lakes" inside the continental areas rather than an ocean of the type of the Pacific Ocean.

Most of the earthquakes originate at depths between five and twenty-five miles. Earthquakes with larger depths occur more rarely and the largest depths observed so far in the interior of the continental area are about 150 miles. Inside the Pacific Ocean earthquakes are rare and no large depths have been observed there so far. The boundary region between the two areas, however, is at the same time a zone in which earthquake origins have been found down to a depth of almost 500 miles. These very deep earthquakes have the peculiar property that, in general, the larger their depth, the more remote they are from the normal earthquake zone area around the Pacific Ocean. This is true for the Japanese region as well as for the Philippines, the central and eastern East Indies, the Fiji and Tonga Islands and South America.

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So far as has been found from the records the mechanism in these deep earthquakes is similar to that of normal shocks. For example, the movements along the San Andreas fault in California during the recent geological time have continued in the same way so, that the area west of the San Andreas fault has moved northwardly as compared with the region east of it. The studies of seismograms recorded at various distances from various sources over the whole world indicate that normally the same mechanism persists over a larger area thus indicating that faulting movements of the type just described for the San Andreas fault have been the same throughout areas of the size of a continent ever since exact records are available. This result is not confined to normal shocks, but in a given region, the same type of displacement in the same direction has been deduced from the earthquakes with deep foci, except that these, as has been mentioned before, occur more inland.

For a long time it was difficult to explain how it may be possible that at large depths, where the material is plastic and is supposed to flow, stresses of a magnitude necessary to produce earthquakes can accumulate. However, it had been overlooked that the viscosity at these depths is so large that plastic flow can occur only very slowly. The accumulation of stresses apparently is faster than the reduction of these stresses by plastic flow, so that finally a point may be reached at large as well as at small depths where the material cannot any longer resist the large stresses so that an earthquake occurs. We do not know yet whether the disturbing forces are centered at large or small depths; but wherever they act, they affect the whole region between the surface and a few hundred miles of depth. As the really deep earthquakes occur only around the Pacific Ocean there can be no doubt about the unique relation between that boundary and the occurrence of these earthquakes. While hitherto it has been considered that geological events are confined more or less to the uppermost crust of the earth these new findings show that even at present the changes in the earth extend very much deeper. Originally, the deep focus earthquakes were considered a more or less disturbing element in our present ideas on the earth's crust and its changes. However, there can be no doubt any longer that with further study and with the completely new way of considering the mechanism of the changes in the earth's crust, there is good hope that a rapid development of our knowledge of the earth will arise from these new results. Study of the history of the Pacific Ocean will probably yield important results concerning the history of the earth, and the investigation of deep focus earthquakes around the Pacific Ocean promises to bring us new clues to the still unsolved problem—we have yet to learn what are the forces which produce earthquakes and mountains.